Progress Report Number 6
Project 2.1
Metabolism and Dosimetry of Plutonium
Industrial Compounds

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Project 2.1
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Executive Summary

The long-term collaborative research project between the Dosimetry Registry of the Mayak Industrial Association (DRMIA), operated by Branch No. 1 of the SRC Institute of Biophysics, and the U. S. Transuranium and Uranium Registries (USTUR), operated by Washington State University, continues into its third year under the sponsorship of the U. S. Department of Energy Office of International Health Programs.

The main purpose of the project is to combine data accumulated by both Registries, create a joint database, and perform a mutual analysis of this unique information regarding metabolism and dosimetry of transuranic nuclides, specifically plutonium and americium, in the human body.

The primary focus of the second year of this collaborative research program was to use the joint USTUR-DRMIA database for a series of tasks involving biokinetic modeling. In the previous progress report, data were presented which suggested that the transportability (solubility) of aerosols from workplaces in plutonium processing facilities at Mayak could be measured in the laboratory. The data also suggested that those measurements would be useful in dose assessments for the workers inhaling the aerosols. Data were presented which related plutonium concentrations in the skeleton and liver and they suggested that disease conditions involving the liver have an effect on the exchange of plutonium between the two organs when compared to liver and skeletal concentrations in healthy workers. Statistical analyses were subsequently performed on those data and the results of those analyses are presented in this report.

Statistical analyses of the relationships between the respiratory tract and systemic concentrations of plutonium in USTUR and DRMIA workers indicated a significant influence of residence time and of transportability (solubility) of inhaled plutonium-containing aerosols on the respiratory tract:systemic concentration ratios. The mean lung:systemic ratios were very significantly different between aerosol groups, indicating a need for separate lung retention and clearance models for each group. The DRMIA lung model, used at Mayak and FIB-1 for dose assessments, was briefly described in this report with separate retention and clearance parameters for each aerosol group. This model will be described more thoroughly and compared to other such biokinetic models in subsequent progress reports. There were few statistically significant differences between mean respiratory tract:systemic concentration ratios of groups of workers categorized on the basis of health impairment. This indicated that the health of workers did not influence the transfer of plutonium from the lung to the systemic circulation.

The health of workers was shown to to have a statistically significant influence on the distribution of plutonium in systemic organs, especially in the liver and the skeleton. Disease conditions of the liver resulted in a significantly reduced plutonium concentration in that organ and a significant increase in the concentration in the skeleton when compared to the concentrations in those organs of relatively healthy workers. Such disease conditions were also shown to significantly increase the urinary excretion of plutonium from the system when compared to the urinary excretion rates of relatively health workers. These results are expected to have a significant impact on organ dose assessment made on the basis of bioassays for urinary excretion of plutonium.

The shielding of a whole-body counter. formerly in use at the U. S. Rocky Flats Plant, was transported to FIB-1 and installed in a building addition which was newly constructed for that purpose. Assembly and installation was completed in November, 1999. During the next reporting period, the refurbished detectors with computer system and software will be installed and the system will be calibrated and put into operation.

One manuscript, An interlaboratory comparison of radiochemical analytical methods for actinide elements in human tissues and bioassay samples, jointly authored by USTUR and DRMIA investigators, is under internal review by the USTUR and DRMIA and will be submitted to a peer-reviewed scientific journal for possible publication.

Progress

In the previous progress report (Khokhryakov et al. 1998b), data relevant to a number of tasks were tabulated with only minimal statistical analyses. Those data were statistically analyzed and the results of the analyses are presented, on a task-by-task basis in this report. Revised versions of many of the tables of the previous report are included in this report as a basis for the statistical conclusions. In general, those tables from which meaningful statistical conclusions could not be drawn were not reproduced in this report.

Task A. Intercomparison of radiochemical analytical methods used by the two Registries for determination of actinides in autopsy samples.

This task was originally planned to be accomplished in three steps;

1. Intercomparison of instrumental methods and equipment for plutonium and americium measurements.

2. Intercomparison of radiochemical separation and measurement methods, and

3. Intercomparison of analyses of Standard Reference Materials (SRM) prepared by the U. S. National Institute of Standards and Technology (NIST).

The results of the first two steps with statistical analyses were presented in previous progress reports (Khokhryakov et al. 1998a; 1998b). Completion of the third step was planned for 1998; however, the DRMIA was not able to import the SRM or the plutonium, americium, uranium, and thorium tracer solutions needed for the analysis. New Russian regulations required a license for receipt of all isotopes of plutonium, uranium. and thorium regardless of the quantity so this reporting period was used to prepare the documents needed to obtain that license. Completion of this task is anticipated at the end of 1999.

Task D. Coordination of radiochemical methods to be used by each Registry to determine plutonium and americium contents of tissue samples.

Task D is one of the most important tasks for the DRMIA. The goals of this task for this reporting period were:

1. development of proficiency, by the DRMIA laboratory personnel, in the use of new radiochemical methods, including new reagents and separation resins, for determination of actinide activity in biosamples,

2. installation of the newly acquired EG&G Ortec OCTETE alpha spectrometry system in

DRMIA laboratories, and,

3. exploration of the use of TRU-Spec resins for radiochemical separations of actinides from biosamples in DRMIA laboratories.

The first two goals have been successfully completed; the third goal has been explored and the use of TRU-Spec resins has been rejected for the time being for two reasons: 1) the TRU-Spec resins are very expensive and not yet applicable for routine analyses performed by the DRMIA and 2) the DRMIA currently has radiochemical methods which are sensitive enough for the activity levels of plutonium and americium in their samples.

As part of Task D, the DRMIA conducted a series of analyses to determine background activities and minimum detectable activity associated with their new radiochemical separations methods and alpha spectrometry system. Background determinations were performed with autopsy samples of bone and soft tissue from Ozyorsk residents. Because of the proximity of Ozyorsk to the Mayak facility, tissues from the Ozyorsk population have actinide contents higher than those which would result from global fallout. The values in the table below are the mean values, with associated standard deviations (SD) of the measurements. The SD reflects the propagated uncertainty associated with radiochemical separation and alpha spectrometry.

| | Background activities (mBq) | | | | | |
| | $^{239+240}$Pu | | ^{238}Pu | | ^{241}Am | |
Sample type	Mean	SD	Mean	SD	Mean	SD
Bone	0.295	0.159	0.027	0.034	0.386	0.215
Soft tissues	0.310	0.203	0.044	0.065	0.364	0.088
Average	0.302	0.180	0.035	0.052	0.375	0.151

The minimum detectable amount (MDA) was determined with the equation (HPS 1996),

$$((4.65 \, S_b) + 3)/ R \, E \, T \qquad \text{where:}$$

S_b = the standard deviation of total background counts,
R = tracer recovery of 0.6 or 60%,
E = efficiency of 0.25, and
T = time of counting (172,800 s).

This resulted in an MDA values of 0.855 mBq and 1.06 mBq for $^{239+240}$Pu in bone and soft tissue samples, respectively, and values of 1.1 mBq and 0.5 mBq for ^{241}Am in bone and soft tissue samples, respectively. Therefore, the overal MDA for plutonium and americium was considered to be approximately 1 mBq per sample with a total uncertainty less than 50%.

According to Russian Federation Orders, About Ensuring the Uniformity of Measurements and About Standardization, the new radiochemical methods with Bio-Rad resins and the use of the EG&G Ortec OCTETE alpha spectrometer must be certified to ensure juridicial significance of the research results in Russia. During this reporting period, the DRMIA has completed several series of trials and prepared the documents needed for this standardization. Also, the DRMIA has begun the process necessary to certify the new radiochemical procedure manual, Alpha spectrometry of plutonium and americium isotopes. Radiochemical methods for determination of low activity levels in biosamples.

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Task E. Analysis of physico-chemical properties of workplace aerosols (such as particle size distribution and in vitro solubility) at the Mayak facility and American facilities for the purpose of more accurately predicting plutonium behavior in the lungs of workers.

In the previous report (Khokhryakov et al. 1998b) and in this report (Task F), the transportability coefficient (S), as measured by the dialysis method, was shown to be related to the transfer of inhaled plutonium compounds from the lung to systemic circulation. The coefficient was shown to reflect the physico-chemical properties of aerosols to which Mayak workers were exposed in various workplaces. The parameter, S, is important for lung dose assessment as well as for in vivo dose assessment, based on analysis of urinary excretion of plutonium.

Considering the recommendations of the Scientific Review Group, further efforts on aerosol solubility will be addressed to a study of the correlation between transportability and particle size distribution as part of Project 2.4.

Task F. Analysis of the dynamics of respiratory tract:systemic concentration ratios from data of both Registries for the purpose of establishing the lung clearance coefficients for plutonium compounds to the systemic circulation.

In the previous progress report (Khokhryakov et. al. 1998b), data presented for task F were intended to show relationships between respiratory organ:systemic plutonium concentration ratios and aerosol transportability and between those ratios and the health status of deceased workers. For this report those data were statistically analyzed using an analysis of covariance followed by, where appropriate, a protected least significant difference test for adjusted means. Summary data indicating the relationships between the respiratory organs: systemic plutonium concentration ratios and the transportability (in-vitro solubility) of aerosols to which Mayak workers were exposed are shown in Table F-1. The aerosol transportability (S) values, used to categorize the respiratory organ:systemic ratios of Mayak workers, were based on measurements of the solubility of aerosols collected in the workplaces of three processing facilities on the Mayak site. The S-value, 0.3, represents the least soluble aerosol, collected in areas in which work was

performed with metallic forms of plutonium; the value, 1.0, was assigned to aerosols of intermediate solubility such as chlorides, oxides, and oxalates; and the value, 3.0, included the more soluble aerosols such as nitrates. Mean respiratory organ:systemic plutonium concentration ratios for USTUR cases were included in Table F-1 although the aerosols to which these cases were exposed were not characterized. More detailed explanations of the aerosol collection and physico-chemical measurement methods were included in progress reports 4 and 5 (Khohkryakov et al. 1998a; Khokhryakov et al. 1998b).

For each aerosol group, the respiratory organ:systemic plutonium concentration ratios were determined to be log-normally distributed so the summary data in Table F-1 are listed in terms of the geometric means (GM) and geometric standard deviations (GSD). The GM and GSD in Table F-1 of this report and those in Table F-1 of the previous progress report (Khokhryakov et al. 1998b)are somewhat different. For the previous report, individual ratios which were determined to be outliers (above or below two GSD from the GM) were excluded from consideration. It was deemed preferable to include those outliers in the statistical analysis for this report. They had little effect on the GM and only minimal effect on the GSD as the outliers were generally distributed both above and below the GM.

Regression of the lung:systemic plutonium concentration ratios against residence times indicated a common regression line slope for the three aerosol transportability groups, i.e.: there were no statistically significant differences between the slopes for each of the groups. The common slope was –0.016 and was statistically different from zero (P< 0.0001); therefore, the data were adjusted for residence times before further analyses were performed. The GM shown in Table F-1 are the non-adjusted least-square mean values although there was only a small difference between those and the adjusted means (Table F-2) because of the very small slope involved.

The protected least significant difference test showed that the mean lung:systemic ratios of the three DRMIA groups and that of the USTUR were all significantly different from one another (Table F-2). Although the mean USTUR ratio indicated that the USTUR cases were exposed to aerosols of transportability groups 0.3 and 1.0, the histograms in Figures F-1 through F-4 indicate exposures of USTUR workers to aerosols of the same range of solubilities as those to which the DRMIA workers were exposed.

The next analysis involved lymph nodes associated with the respiratory tract. Although regression of the lymph node:systemic plutonium concentration ratios against residence time resulted in a regression line with a slope which was not significantly different from zero (P=0.35), the data were adjusted for residence time to maintain consistent methodology for the respiratory tract organs. As expected, non-adjusted and adjusted mean ratios in Tables F-1 and F-3, respectively show very little influence of residence time. However, the adjustment required exclusion of USTUR cases for which no residence times were available; therefore, the number of USTUR cases was smaller in Table F-1 of this report than they were in Table F-1 of the previous progress report (Khokhryakov et al. 1998b). The comparisons of adjusted mean ratios shown in Table F-

3 indicate that the lymph node: systemic mean plutonium ratios of the aerosol transportability groups were all statistically significantly different from one another, including the USTUR group for which no aerosol transportability data were available.

A similar analysis was performed with the respiratory tract:systemic concentration ratios by aerosol transportability group. The respiratory tract included lungs and the associated lymph nodes. The regression of ratios against residence time resulted in a regression line with a slope of -0.011 which was significantly different from zero ($P=0.032$) so the data were, again. adjusted for residence time. The comparison of adjusted mean respiratory tract:systemic ratios is shown in Table F-4. Mean ratios of all groups were significantly different from one another with one exception; there was not a significant difference between the USTUR workers and those of DRMIA transportability group 1.0. The reason for that is simply that the USTUR mean ratio corresponds closely with that for group 1.0 and the USTUR ratios range over several orders of magnitude as noted in the histogram of lung:systemic ratios shown in Figures F-1 through F-4.

The DRMIA respiratory organ:systemic plutonium mean concentration ratios shown in Table F-1 indicate the importance of knowledge of physico-chemical properties of aerosols to which workers were exposed. Such information can be inferred from the workplace histories of workers as was shown in Table E-1 of the previous progress report (Khokhryakov et al. 1998b). Aerosol transportability information could prevent serious under- or over-estimation of lung and systemic organ radiation doses from plutonium.

Because the long-term regression slopes for lung:systemic concentration ratios in the three DRMIA aerosol transportability groups were not statistically different, the major influence of aerosol transportability can be assumed to occur during the first years after exposure. Most USTUR and DRMIA workers had residence times between 10 and 50 years. The very significant differences between lung:systemic mean concentration ratios during that time period indicates the need for separate lung biokinetics models for workers in each of the aerosol transportability groups. Physico-chemical properties of aerosols inhaled by USTUR workers are generally not available; however, the information shown in Figures F-1 through F-4 may be useful for retrospectively stratifying USTUR workers into aerosol transportability groups corresponding to those of DRMIA workers, at least into the highest and lowest transportability groups. The same kind of retrospective stratification could be applied to Mayak workers whose work histories are not known.

Another aspect of Task F was the investigation of the effect of disease on the movement of inhaled materials from the lung to systemic circulation. Definitions of the health groups used in this study are included under Task G, below. Respiratory tract organ:systemic plutonium concentration ratios were used for this investigation and mean ratios for lung:system. lymph node:system, and respiratory tract:system were given in Table F-2 of the previous progress report (Khokhryakov et al. 1998b). A revised version of that table is included in this report (Table F-5). The original table included only the DRMIA data from workers in aerosol transportability groups 0.3 and 1.0. However, USTUR workers were included in all three transportability groups (Figures F-1 through F-4) so all DRMIA

lung and respiratory tract data were included in Table F-5 of this report and used in the statistical analyses. Data for lymph nodes, alone, were not statistically analyzed for this report and are not included in Table F-5. The data were, as before, adjusted for residence time for the statistical analyses; therefore, USTUR cases for whom that information was not available were excluded and the number of cases is smaller in Table F-5 than in Table F-2 of the previous report. Data for lymph nodes alone were not changed from the original and were not statistically analyzed for this report.

Analysis of the adjusted mean lung:systemic ratios for the three health groups indicated no statistically significant differences between USTUR health groups or between DRMIA health groups. When the data were combined, however, statistically significant differences between the three groups were noted as shown in Table F-6. The mean from Health Group 1, relatively healthy individuals, was significantly different from those of Health Groups 2 (p=0.044) and 3 (p=0.048). Group 2 included workers with disease conditions not involving the liver and Group 3 included those workers with marked liver disease. Analysis of the respiratory tract:systemic ration (respiratory tract includes the lungs and associated lymph nodes) indicated no significant differences between ratios for the three health groups of either Registry, alone, or in the combined data.

Physiologically, it is not likely that pathology of organ systems other than the respiratory system might affect the removal of plutonium from the lung. In the USTUR cohort, at least, most of the workers had carried actinide lung burdens for many years before death and, except in cases where the inhaled material may have been highly insoluble, little of the initial actinide deposition remained in the lung at the time of death. Two pathologic conditions, potentially present in both Health Groups 2 and 3, could influence translocation of plutonium from the lung many years after the initial deposition. One is pulmonary fibrosis (pneumosclerosis) which could sequester plutonium particles in the lung; another is lung cancer. Malignancies growing in the lung tend to displace normal lung tissue and, potentially with it, the plutonium it contains. Cases of lung cancer would be classified in Health Group 2 if there were no metastases to the liver and they would be classified in Health Group 3 if the liver were involved. Either way, they could influence the translocation of actinides from the lung. Further research as part of Task F should include evaluation of the influence of pulmonary fibrosis and lung cancer on the lung:systemic plutonium concentration ratios of both Health Groups 2 and 3.

The statistical analysis above indicated no significant differences between slopes of lung:systemic plutonium concentration ratios regressed against residence times although the ratios were collectively time-dependent and there were significant differences between groups of ratios based on the transportability of aerosols to which the workers were exposed. The results of another approach to differentiating between ratios of the three transportability groups are shown in Figure F-5. In those graphs, the lung:system ratios were regressed against the time between cessation of work with plutonium to death, time (). Those graphs suggest a difference between regression slopes for the transportability groups as well as differences between the three groups of DRMIA ratios.
The graphs also indicate the possibility of creating a lung clearance model, based on

autopsy data, which accounts for the influence of both time and transportability on transfer of plutonium from the lung.

Autopsy data on the dynamics of the lung:system ratios over time after inhalation were used for determination of parameters in a biokinetics model of the respiratory tract. For most DRMIA and USTUR cases. the time between inhalation of plutonium and death exceeded 10 years. This permits an assumption that the autopsy data correspond to plutonium distribution at the later, slower stages of metabolism and the behaviour of radionuclide deposited in the respiratory tract can be described by a simplified model without consideration of the initial, rapid biokinetics processes. Figure F-6 is a schematic diagram of the simplified lung model that was used by the DRMIA and the Mayak Production Association for dose assessment at long times after the beginning of work with actinide elements. The model describes the behavior of plutonium in the lung, including the alveolar and tracheo-bronchial regions, by the use of three compartments (k_f, , and) where:

K_f = the fraction of lung-incorporated plutonium that forms a fixed deposit,
 = the fraction of plutonium instantly absorbed from the lung to the blood, and
 = the fraction of plutonium that is slowly absorbed from the lung to the blood.

At the time of inhalation of activity, these three parameters are related such that k_f + + = 1. The model also includes a fraction of lung-incorporated material which slowly transfers from lung to tracheo-bronchial lymph nodes, k_n, and a fixed deposition of the nuclide in the tracheo-bronchial lymph nodes, Q_n.

In the model, plutonium biokinetics are described by a system of three first order differential equations for the respiratory tract and ten equations for plutonium retention and excretion from the system. The system of 13 differential equations, with known exposure conditions has. as its solution, the parameters k_f, , and k_n. Calculations were performed individually for each of the three DRMIA transportability groups and for the USTUR group for which physico-chemical properties of inhaled aerosols were not available. The resultant values of k_f, , k_n, and , the lung clearance rate constant, are shown in Table F-7. The values in Table F-7 illustrate the effect of transportability on respiratory tract biokinetics. Less soluble forms of plutonium (S = 0.3) were characterized by the highest values for the slow removal fraction (= 63.0 $\pm$ 35.9 %) and the fixed deposition (k_f = 5.0 $\pm$ 3.52 %) and. inversely, the lowest values of these parameters for the relatively soluble forms (S = 3.0). Not unexpectedly, both parameters are several times higher for the less soluble material than for the more soluble material. In spite of the high variances associated with the parameters. there were significant differences between the transportability groups. based on t-tests for which the results are shown in Tables F-8 through F-11.

The parameters obtained for USTUR cases with unknown transportability and poorly documented exposure histories cannot be directly related to those of any single DRMIA transportability group. but fall within the range of data for Russian cases. As shown in

Figure F-1, USTUR workers were apparently exposed to aerosols of a wide range of solubilities. The relatively high uncertainties associated with the DRMIA parameters are likely a result of many factors including insufficient and, in some cases mistaken, information about exposure histories. Also, the model contains a simplified assumption regarding the absence of lung clearance processes at early and intermediate times after exposure, characterized by several days to 2 years, that is described in the ICRP-66 lung model (ICRP 1994). This indicates that it is important to study the histories of exposures of workers in the archives of the Mayak Production Association and in the FIB-1 clinic to learn more about the role of the intermediate and early phases on lung doses.

As shown in Table F-5, the means of the lung clearance variable, , increased from 0.099 y^{-1} (2.7 X 10^{-4} d^{-1}) for the group exposed to the less soluble aerosols to 0.190 y^{-1} (5.2 X 10^{-4} d^{-1}) for the group exposed to the more soluble aerosols. These values exceeded the value recommended by the ICRP-66 model (10^{-4} d^{-1}) for compounds of class S, slowly clearing materials, which means that lung clearance in the DRMIA workers was faster than that predicted by the ICRP. However, the existence of the fixed deposition of plutonium in the lungs of all three groups of workers would lead to a higher organ dose.

A detailed description of the methods used to derive the parameters of the DRMIA respiratory tract model and a comparative analysis of this model with that of the ICRP is planned for the next progress report.

Task G. Determine the relationships between actinide concentrations of organs of the body and between individual organs and total body burdens in healthy individuals as well as in those with health impairment, specifically those with liver diseases.

In the last progress report (Khokhryakov et al. 1998b), systemic plutonium concentrations in healthy workers as well as in those with liver diseases were studied. DRMIA and USTUR cases were classified into three groups according to disease conditions and causes of death.

Health Group 1 included workers who were relatively healthy at the time of death and the causes of death in those cases were generally accidents, suicides, or, in some cases, an acute cardiovascular accident. At autopsy, livers of this group usually showed only slight signs of protein dystrophy.

Health Group 2 included workers who died of chronic cardiovascular diseases or malignant tumors of any organ (except liver), without multiple metastases to the liver. Livers of this group were generally characterized by moderate fatty degeneration of hepatic cells.

Health Group 3 included workers who died of carcinoma of the liver, cirrhosis of the liver and tumors of other organs with multiple, massive metastases to the liver. At autopsy, morphological changes in the liver of these cases were characterized by marked fatty

degeneration of liver tissue.

Table G-1 of the previous report (Khokhryakov et al. 1998b) contained geometric mean organ:systemic plutonium concentration ratios, with GSD, for a number of tissues and organs including the liver, skeleton, spleen, testes, thyroid, kidneys, heart, and skeletal muscle, grouped on the basis of health group. Table G-1 of this report is a revision of the previous table and contains mean ratios for the two organs expected to contain the greatest depositions of plutonium, the liver and the skeleton. Statistical analysis of these data determined that the ratios were normally distributed so arithmetic means and standard deviations were more appropriately used than GM and GSD. It was also determined that there was a statistically significant influence of residence time so the data were adjusted for that parameter. As a result, the USTUR sample became somewhat smaller because cases for whom residence times were not available were excluded from the analysis.

A statistical analysis of the DRMIA mean liver:systemic ratios of the three health groups (Table G-1) indicated that the mean ratios were all very significantly different from one another (P<0.0001). The USTUR mean ratios of Health Groups 1 and 2 were significantly different from that of Health Group 3 as shown in Table G-2; however, means of Groups 1 and 2 were not significantly different (P=0.14). When data of the two Registries were combined, all mean ratios were significantly different from one another (P<0.0001). The liver:systemic ratios of Health Group 2 were lower than those of Group 1 and lowest in Group 3, indicating a significant effect of disease conditions, especially liver disease, on the retention of plutonium in the liver.

An inverse trend was shown with the skeletal:systemic plutonium concentration ratios (Table G-1); they were smallest for Health Group 1 and greatest for Health Group 3 indicating an effect of health status on skeletal concentrations as well as those of the liver. Mean DRMIA skeletal:systemic ratios for each of the three health groups were significantly different from one another (P<0.0001). The USTUR mean ratios for Health Groups 1 and 3 were significantly different (P=0.0084); however those of Groups 1 and 2 and Groups 2 and 3 were not (Table G-3). Means of the combined data were all very significantly different from one another (P<0.0001).

Directly comparing the mean plutonium concentration in the skeleton and the liver gave much the same result as for skeleton:system. DRMIA means and means of the combined data were all significantly different from one another (P<0.0001) while only the USTUR means of Health Groups 1 and 3 were significantly different (Table G-5).

It appears, from this investigation, that plutonium concentrations in the skeleton and liver are inversely related and disease conditions that result in the loss of plutonium from the liver result in an increased concentration in the skeleton. Calculation of fractions of systemic content located in the tissues of the bodies of DRMIA workers (Table G-6) shows that the fractions in the livers and skeletons of Groups 1 and 2 approximate the ratios, 50:30, proposed by the ICRP (1986; 1993). The skeleton:liver content ratio was quite different for Group 3 and did not correspond to ICRP models. In addition to the

shifting of plutonium from liver to skeleton, there was also an increase in urinary excretion of plutonium in the health-impaired individuals and that is the subject of Task H, below.

Task H. Quantitate the relationships between actinide contents of the lungs and body organs at autopsy and the long-term, temporal pattern of urinary excretion in healthy individuals and in health-impaired individuals.

All of the data presented as part of this task in this report are those of the DRMIA. The USTUR is currently in the process of receiving urinary excretion data for its long-deceased registrants from laboratories throughout the U. S. and entering those data into the USTUR database. It was considered advantageous to wait until all useful data could be included in the analyses rather than began an analysis with only partial data.

In the previous progress report (Khokhryakov et al. 1998b) it was shown that the DRMIA had urinary excretion data from 155 of their autopsy cases with plutonium content greater than their minimum level of detection. They showed the distribution of a urinary excretion factor, K_e, for plutonium among 27 relatively healthy individuals. The plutonium excretion factor was estimated on the basis of urine bioassays related to analyses of tissues collected at autopsy of former Mayak workers, such that $K_e = U/Q_s$ where :

U = the activity of plutonium excreted in urine per day, and
Q_s = the systemic plutonium content determined at autopsy.

For the cases used in the Task H study, autopsies were performed within two years of the last bioassay performed on an individual. Such data are unique in that very little information exists about urinary excretion of plutonium at long times after exposure, especially related to actual systemic content.

The urinary excretion data of those 27 individuals (with 3 more cases added) is presented in Table H-1 of this report. Those data indicate a geometric mean excretion rate, K_e, of 1.54 ± 1.7 (GSD) X 10^{-5} d^{-1}, which is consistent with values obtained by other investigators. Jones (1985) and Leggett (1985) cited excretion rates of 1.11 X 10^{-5} d^{-1} and 1.97 X 10^{-5} d^{-1}, respectively. In the data of Table H-1, no correlation was found between the excretion rate, K_e, and transportability, S, or aerosols inhaled or between K_e and time after exposure or age of the individuals. The GSD of Table H-1 and the histogram of Figure H-1 show considerable variability in excretion rates; however, this is consistent with the data of Moss et al. (1969).

Another aspect of Task H is to show a relationship between plutonium daily excretion rates and the health state of the individuals. This relationship was previously described by Khokhryakov et al. (1994) and Suslova and Khokhryakov (1994). Table H-2 shows the values of GM $\pm$ GSD for individuals grouped according to health group, defined above. Those data show that groups of individuals with impaired health excreted plutonium at a more rapid rate than did the healthy individuals of Group 1. Even with the relatively large

GSD, the differences between group means were statistically sig
nificant as shown in Table H-3.

The assessment of plutonium body burdens based on the urinary excretion rate is a tool
used in both Russian and U. S. processing facilities. The data of Tables H-1 and H-2
indicate that using K_e without consideration of the health state of an individual could lead
to a serious under- or over-estimation of plutonium body burden and to dose and risk
estimates based on the bioassay. Indeed, this is an important consideration with respect to
radioepidemiologic studies, specifically to Projects 2.2 and 2.3. In individuals of Health
Group 3, for example, the K_e would suggest a higher than actual systemic burden. That
would especially impact dose estimates for the liver as plutonium concentrations in the
livers of individuals of Group 3 were shown to have significantly lower liver
concentrations than those of Group 1 (Task G, above).

In the next progress report, the relationships between lung:systemic ratios and the long-
term temporal pattern of plutonium excretion in healthy individuals will be investigated.

Task I. Enhance the sensitivity of the in vivo counter used by the DRMIA and perform
calibrations and intercomparisons with other, similar facilities to make the facility more
useful for more precise characterization of the intake and retention of actinide elements by
Mayak personnel.

The DRMIA has obtained modern in-vivo counting equipment which was formerly used at
the U. S. Rocky Flats Facility. The shield was received by the DRMIA in October, 1998
and it was installed in a newly constructed facility at the DRMIA laboratories. Installation
was completed by 2 November, 1998 under the direction of American specialists R. Radev
and M. Keck. There were initially problems with opening and closure of the shield door,
which apparently resulted from shipment; however, those problems were subsequently
solved during installation of the electro-mechanical drive mechanism.

Installation of the detectors, electronic equipment, and software are expected to be
completed in June, 1999 under the direction of D. Hickman, LLNL. Project 2.1 personnel
are arranging for shipment of appropriate phantoms so that calibration of the facility can
be can be accomplished with the assistance of S. Glover, USTUR, and D. Hickman,
LLNL. It is anticipated that the facility will be fully operational by July, 1999.

Milestones and Deliverables

1. A report presented to the Joint Coordinating Committee for Radiation Effects Research,
   their Executive Committee, and the joint U. S.-Russian Scientific Review Groups in
   Moscow, Russian Federation on 29 April 1999 by R. E. Filipy and V. F.
   Khokhryakov.

2. A manuscript, An interlaboratory comparison of radiochemical analytical methods for actinide elements in human tissues and bioassay samples. Filipy, R. E.; Glover, S. E.; Suslova, K. G.; Alldredge, J. R.; Orlova, I. A.; Stuit, D. B.; Chernikov, V. I.; Khokhryakov, V. F.; Kathren. R. L. To be submitted to Radiation Protection Dosimetry.

3. A report to a special session of the American Academy of Health Physics on 29 June 1999 by R. E. Filipy.

4. Shipping and installation of the whole-body counter detection and electronic equipment and software with calibration of the facility for full operation by August, 1999.

5. Comparison of biokinetics parameters. obtained as a result of Project 2.1 activities with currently existing biokinetic models for actinide elements such as those proposed by the ICRP.

6. Semi-annual Project 2.1 progress report for the period 16 March – 30 September 1999.

Other relevant information, including relevant trip reports, obstacles to completion of work outlined in FY work proposal. unexpected costs.

Four Russian scientists, V. F. Khokhryakov, K. G. Suslova, E. E. Aladova, and V. V. Vostrotin, visited USTUR facilities for one week in February 1999. During that visit, the material for this progress report was compiled and sections of the report were assigned, by mutual agreement, to USTUR and DRMIA individuals. A proposal for continuing Project 2.1 was also outlined in that the current project is scheduled for completion in March, 2000. The following week, the Russian scientists, together with R. E. Filipy, R. L. Kathren, and J. J. Russell traveled to Salt Lake City, Utah to participate in a workshop, Modeling and Dosimetry of Plutonium in Humans, which was coordinated by Project 2.4 investigators at the University of Utah.

Some obstacles to the completion of Tasks A and I still remain. To complete Task A, the DRMIA must receive Standard Reference Materials from the U. S. National Institute of Standards and Technology. The Russian government has decreed that FIB-1 must obtain a license to receive those materials and the documentation was prepared to obtain the license which is anticipated within the next few months. To complete Task I, the DRMIA must obtain whole-body phantoms from the U. S. DOE phantom library, administered by PNNL in Richland, WA. PNNL requires proof of authorization to receive the phantoms for compliance with customs regulations of both countries. Hopefully, both of these problems will be solved simultaneously as the DRMIA receives their license from the Russian government.

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